

Analysis of Near-Surface Oceanic Measurements Obtained during the Low-wind Component of the Coupled Boundary Layers and Air-Sea Transfer (CBLAST) Experiment

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LONG-TERM GOALS

To quantify and understand the processes that control the vertical transport of momentum and heat beneath the ocean surface.

To evaluate and improve subgridscale parameterizations of the vertical transport processes.

To incorporate the improved parameterizations into routinely applied numerical simulations of oceanographic processes.

OBJECTIVES

To close momentum and heat budgets spanning the air-sea interface using direct-covariance measurements of the turbulent fluxes on both sides of the interface.

To quantify the characteristics of Langmuir circulations and understand their relationship to wind and wave forcing.

To quantify understand the relative importance of shear-generated turbulence, buoyancy, Langmuir circulations, and wave breaking in accomplishing vertical transport of momentum and heat beneath the air-sea interface.

To quantify the dominant balances in the turbulent kinetic energy and temperature variance equations.

To evaluate the Mellor-Yamada, k - ϵ , KPP, and k - ω turbulence closure models.

APPROACH

The approach is to use atmospheric and oceanic measurements obtained during the low-wind component of the Coupled Boundary Layers and Air-Sea Transfer (CBLAST) program. Trowbridge and Plueddemann are focusing on turbulence statistics and Langmuir circulations, respectively, and are

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collaborating with Jim Edson (University of Connecticut), who is responsible for the analysis of atmospheric turbulence measurements obtained during CBLAST; Ming Li (University of Maryland), who is carrying out large-eddy simulations of the oceanic flows observed during CBLAST; and Greg Gerbi, a doctoral student in physical oceanography in the educational program offered by the Massachusetts Institute of Technology (MIT) and the Woods Hole Oceanographic Institution (WHOI), who is funded by this project and is working under the supervision of Trowbridge.

WORK COMPLETED

The CBLAST-low measurement program was conducted at the Martha's Vineyard Coastal Observatory (MVCO), a site exposed to forcing from the open ocean and located off the southern coast of the island of Martha's Vineyard, in Massachusetts. The MVCO consists of a shore laboratory, a meteorological mast located on the beach, a bottom-mounted "seanode" at a water depth of 12 m, and the Air-Sea Interaction Tower (ASIT), at a water depth of 15 m, which was constructed with CBLAST-low funding during 2002. The intensive observational period for the CBLAST-low program occurred during summer and fall of 2003.

Atmospheric measurements from the ASIT during CBLAST-low were obtained from a vertical array of co-located coherently sampled sonic anemometers, temperature sensors, humidity sensors, and static pressure sensors (Figure 1a). These measurements provide vertical profiles of the momentum, sensible heat, latent heat, kinetic energy, pressure and scalar variance fluxes, as well as dissipation rates for turbulent kinetic energy, temperature variance, and humidity variance estimated from inertial-range spectra. Mean profiles of temperature, humidity and velocity were obtained from a profiling package that moved between 2 and 14 m above mean sea level and additional fixed sensors between 3 and 22 m above MSL. The downwelling radiative heat fluxes were measured by solar and infrared radiometers. The skin temperature and the upwelling IR radiative heat flux were obtained from a pyrometer. The heat fluxes are combined to compute the net heat flux into or out of the ocean.

Oceanic measurements during CBLAST-low were obtained from instruments mounted on and near the ASIT, and from sensors routinely maintained as part of the MVCO. Oceanic turbulence measurements were obtained from near-surface and near-bottom horizontal arrays of co-located coherently sampled acoustic Doppler velocimeters (ADV) and thermistors (Figure 1b). These measurements provide inertial-range estimates of dissipation rates for turbulent kinetic energy and temperature variance, as well as direct covariance estimates of turbulent momentum and heat fluxes. Measurements of horizontal velocity at the sea surface were obtained with a "fanbeam" acoustic Doppler current profiler (ADCP), which produces spatial maps of the surface velocity along four acoustic beams (Figure 1c). These measurements will produce estimates of LC intensity and scale from patterns of divergence and convergence of the surface velocities. Bottom mounted ADCPs near the ASIT and at the nearby seanode measured vertical profiles of horizontal velocity through the water column. Near surface profiles of velocity, temperature and salinity were obtained from a high-resolution ADCP and conductivity-temperature-depth (CTD) sensors at the ASIT. Surface displacement was measured at the ASIT using downward looking laser and microwave altimeters. Directional wave spectra are estimated from the ADCP measurements at the seanode.

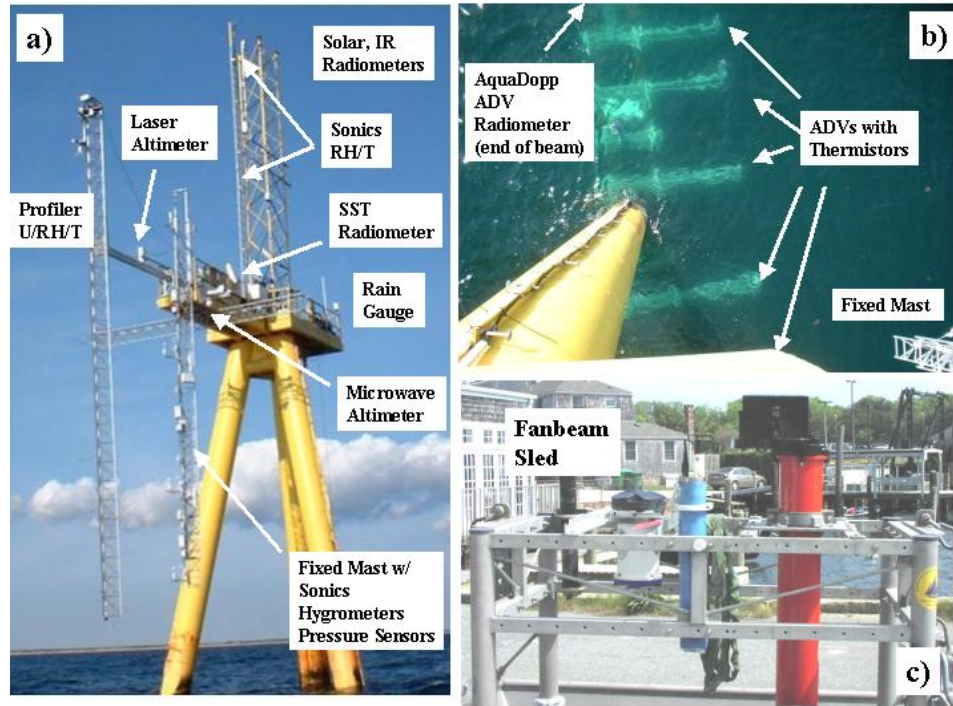


Figure 1. Experiment setup for the ASIT during CBLAST.

[a) The air-side instrumentation deployed on the meteorological tower, fixed array, and profiling mast. The solar and infrared radiometers were 22 m above mean sea level. b) The ocean-side instrumentation deployed on a horizontal beam which was 4 m below the water surface. The depth of the acoustic Doppler velocimeters (ADV) was 2 to 4 m below the ocean surface, depending on the tide. c) The Fanbeam sled that was deployed on a bottom frame just south of the ASIT at a depth of 15 m.]

RESULTS

Measurements of water velocity at the sea surface from the fanbeam ADCP show patterns of convergence and divergence at scales of a few tens of meters (Figure 2), which can be used to identify Langmuir circulation (LC). When winds are moderate and waves are small or decaying, LC is typically poorly developed (left panel). However, LC is clearly distinguishable under similar wind speeds when the wave field is growing. (right panel). Modulation of LC strength during CBLAST-Low appears to be strongly related to wind direction, emphasizing the role of Martha's Vineyard in controlling the wave fetch (e.g. winds from the W, N and NE are fully or partially blocked by the island, whereas winds from the south produce well developed seas).

Examples of directional wave spectra produced from the MVCO seanoode ADCP (Fig. 3) illustrate the complexity of wave conditions at the site. With winds from the S (left panel), a well defined wind-wave peak is evident (however, it is notable that the dominant spectral peak is from lower-frequency swell). As winds veer to the W (right panel), the spectrum consists of a swell peak, a decaying wind-wave peak, and very short fetch, growing wind waves that do not appear above the noise threshold of these spectral estimates.

Future work will examine the relationship of LC strength to surface forcing by wind and waves, with particular attention to the influence of the wave age parameter C_p / u^* , where C_p is the phase speed of the locally-forced wind waves and u^* is the oceanic friction velocity. Partitioning of the wave spectrum into forced wind-waves, decaying wind waves and swell will be a key aspect of the study.

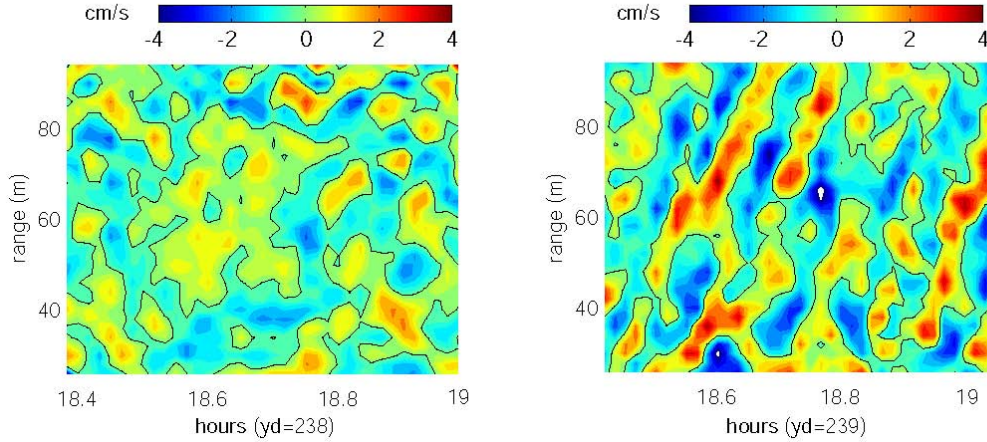


Figure 2. Time-range plots of water velocity at the sea surface based on fanbeam ADCP measurements during CBLAST-Low.

[Near 1800 h on yearday 238 (26 August, left panel) winds were near 5 m/s, but the wave field was decaying, and Langmuir circulation (LC) was not evident. Near 1800 h on the next day, with steady winds near 6 m/s and notable wave growth, LC was well developed.]

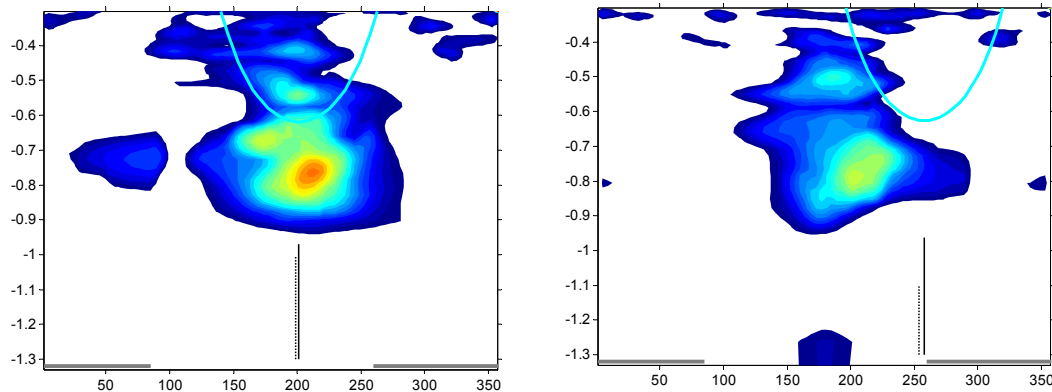


Figure 3. Directional wave spectra at the MVCO seanode for yearday 239 (27 Aug).

[The first spectrum (left panel) shows a dominant swell peak and a modest wind-wave peak (enclosed in magenta hyperbola) associated with winds from the S (vertical lines). Several hours later (right panel), winds have shifted to the W and are blocked by Martha's Vineyard. The swell peak and a decaying wind wave peak are still evident, but wind waves associated with the new wind direction (e.g. within hyperbola) are not evident.]

Direct covariance estimates of the turbulent Reynolds shear stress on the air and water sides of the air-sea interface are approximately consistent in sign and magnitude (Figure 4), although the water-side stresses are consistently smaller than the air-side stresses by a factor of approximately 1.8. The water-side estimates of stress are determined by means of filtering techniques to remove spurious wave effects. To our knowledge, this work represents the first successful attempt to close a momentum balance across the air-sea interface by means of direct-covariance estimates of air- and water-side stresses. Future work will attempt to explain and reduce the variability of the water-side stress estimates, to understand the discrepancy between the magnitudes of the air- and water-side stresses, and to extend the analysis to include a heat balance spanning the air-sea interface.

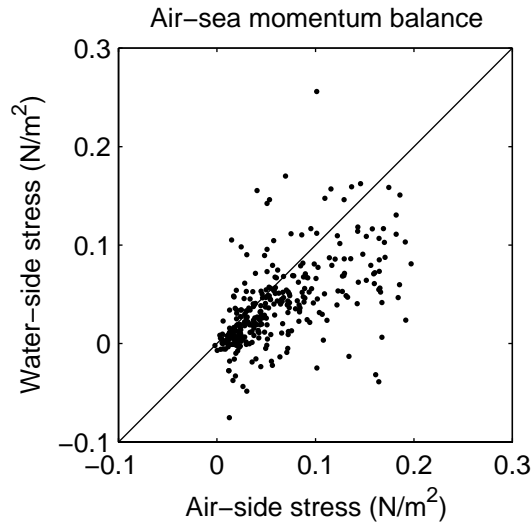


Figure 4. Test of a momentum balance across the air-sea interface.
[Estimates of turbulent Reynolds shear stresses on both the air- and water-sides of the air-sea interface are based on direct-covariance calculations. For this calculation, the number of samples is 327, the squared correlation coefficient is 0.31, and the regression coefficient is 0.56 ± 0.05 at 95% confidence.]